Attributing Regional Patterns of Long-term Ocean Variability in Satellite-derived Observations

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Regional patterns of in sea level trends derived from satellite altimetry observations are linked with long-term variability in surface winds during the 1993-2006 period. Least-squares trends computed from weekly sea level anomalies (SLA) derived from satellite altimetry observations (Figure 1) show large-scale regional patterns. These regional changes reach values that can be several times higher the global-mean trend of 3 cm/decade (Cazenave and Nerem 2004). The patterns of SLA change during the 1993-2004 have been linked with changes in temperature, salinity, and mass using a general circulation ocean model constrained by observations (Wunsch et al. 2007); however these changes have not been linked with changes in wind forcing. The most striking regional feature is found in the Pacific, where significant trends of up to 10 cm/decade are detected in the western tropical Pacific. Regional patterns of sea level change are also identified along the western boundary currents (WBCs) in all oceans.

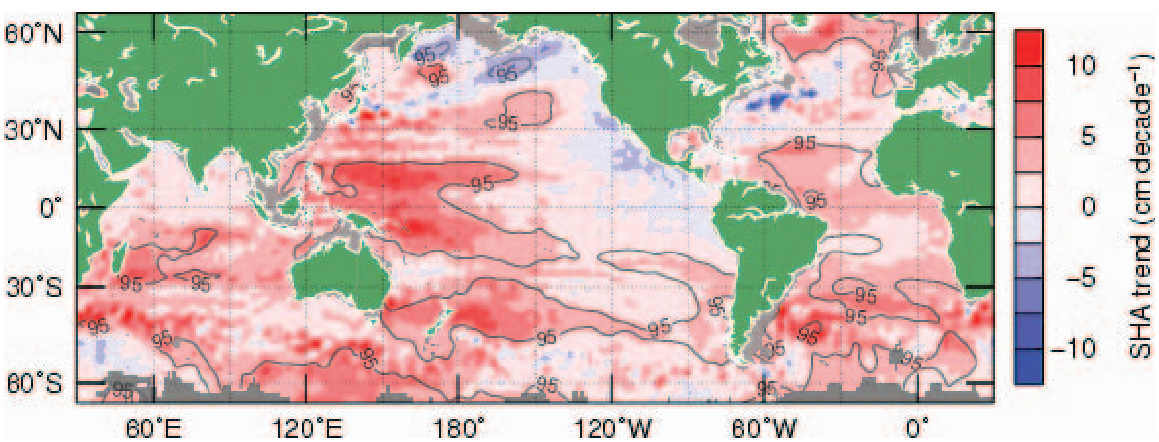

Figure 1 – Least-squares trend of altimetry-derived sea level anomalies (SLA) derived from satellite observations during the 1993-2006 period. Contours indicate regions where the SLA trends are significant with 95% probability.

Trends in eddy kinetic energy (EKE) are also computed using the altimetry-derived SLA data in order to determine whether the patterns of sea level change are associated with changes in the position or strength of surface currents, which are expected to have a signature on the EKE trends, or result from large-scale wind or buoyancy forcing, which have a larger spatial scales resulting in much weaker spatial gradients. The trends in EKE (Figure 2) indicate that the sea level changes identified over all WBCs are consistent withchanges in ocean currents. For instance, the EKE trends are positive over the Kuroshio extension region, an indication of a possible increase in velocity of this current. An increase in velocity should also result in incr eased meridional gradient in sea level to satisfy geostrophic balance. This is consistent with the SLA trends, which show two bands of increased and decreased SLA south and north from the axis of the current respectively. The SLA and EKE trends indicate a southward shift of the East Australian and the Brazil currents. The band in reduced SLA along the axis of the Gulf Stream indicates a southward shift, which is consistent with the trend in EKE.

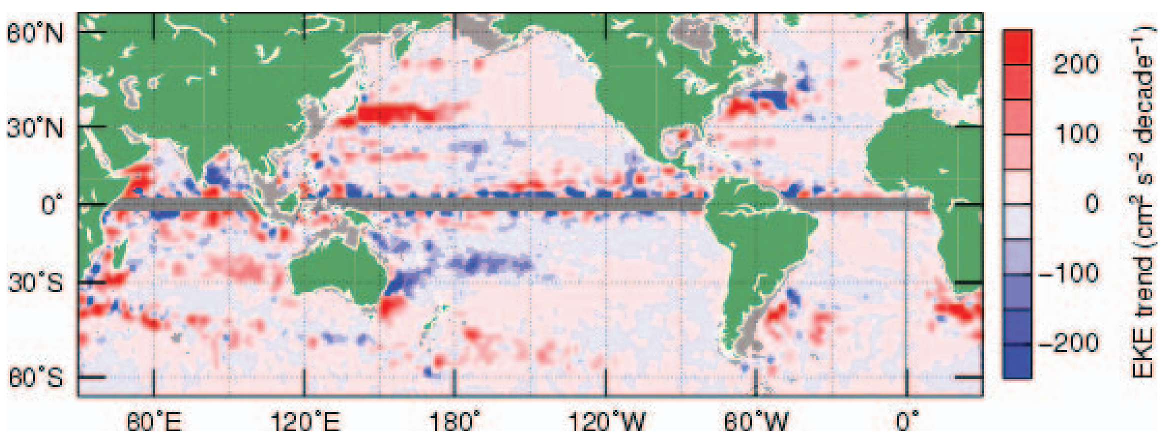

Figure 2 – Least-squares trend of eddy kinetic energy (EKE) computed from altimetry-derived sea level observations for the 1993-2006 period. Contours indicate regions where the trends are significant with 95% probability. The EKE trends are not shown in the equatorial band between 5ºN and 5ºS because EKE cannot be computed near the equator due to lack of geostrophic balance.

The trends in surface wind stress and wind stress curl (WSC) for the 1993-2006 period (Figure 3) reveal patterns that could explain the changes in sea level and circulation identified in tropical Pacific and the WBCs. Adjustment of the equatorial thermocline to the strengthening of the trade winds observed along the equatorial Pacific could explain the increase in SLA over the western tropical Pacific. This is confirmed by results obtained by forcing a reduced-gravity shallow water model on an equatorial β-plane with the wind changes. The spatial correlation between the change in sea level simulated by this model and the observed changes over the tropical Pacific (30ºN-30ºS) is 0.6. For the WBCs, the SLA trends are compared with results obtained by forcing a reduced-gravity shallow water model on an mid-latitude β-plane with the wind changes confirming the hypothesized shifts or changes in speeds in the currents.

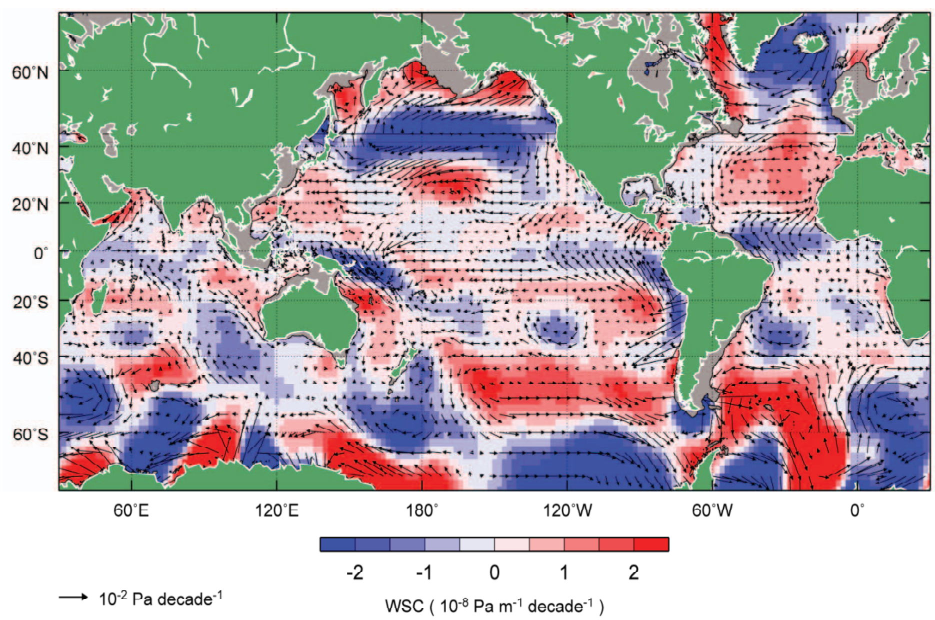

Figure 3 – Least-squares trend of surface wind stress (arrows) and wind stress curl (colors) computed from the NCEP/NCAR reanalysis for the 1993-2006 period.

These results attribute striking regional sea level changes identified in satellite observations to changes in atmospheric circulation. These changes in atmospheric circulation, such as the strengthening of the trade wind in the equatorial Pacific, are not related to global warming, but are more likely a result of decadal variability internal to the climate system. These changes are superposed on sea level rise due to warming of the world oceans. The changes in the western tropical Pacific are especially interesting because islands in this region are extremely vulnerable to sea level rise. However our results indicate that the bulk of the sea level rise experienced during the 1993-2006 period is likely to result from the adjustment of the equatorial thermocline to decadal changes in atmospheric circulation that may not be related to Global Warming.

References

Cazenave, A., and R. S. Nerem, 2004: Present-day sea level change: Observations and causes. *Rev. Geophys.*, **42**, RG3001, doi:10.1029/2003RG000139.

Wunsch, C., R.M. Ponte, and P. Heimbach, 2007: Decadal Trends in Sea Level Patterns: 1993–2004. *J. Climate*, **20**, 5889–5911.